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FAA Health and Usage Monitoring System (HUMS) Research and Development

Dy Le

Rotorcraft Program Manager

Airport & Aircraft Safety Division

Airworthiness Assurance R&D Branch

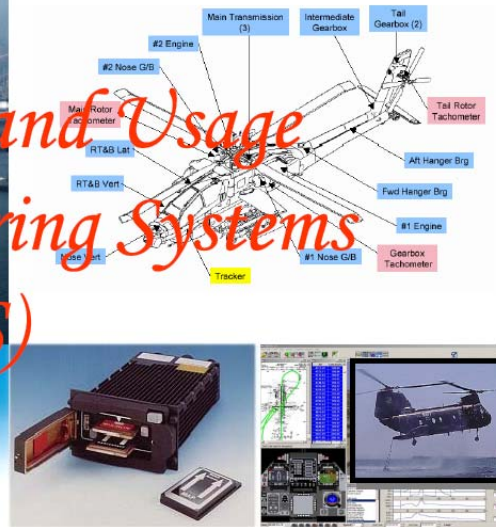
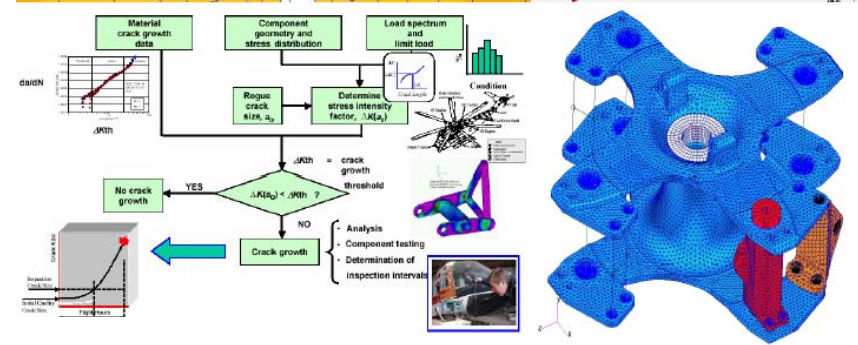
FAA William J. Hughes Technical Center

February 15, 2005

Presentation Outline

- ➔ Overall FAA Rotorcraft Structures Research
 - ➔ HUMS R&D Requirements
- ➔ Highlights of Process and Criteria Used to Develop HUMS R&D Needs
- ➔ Overview of FAA HUMS R&D Roadmap
 - ➔ HUMS Advisory Circular (AC) Requirement Compliance Demonstration
 - ➔ Development of HUMS Operational Requirements
 - ➔ Commercial HUMS Validation
 - ➔ Onboard Warnings
- ➔ FAA BAA Contract Opportunity Plan

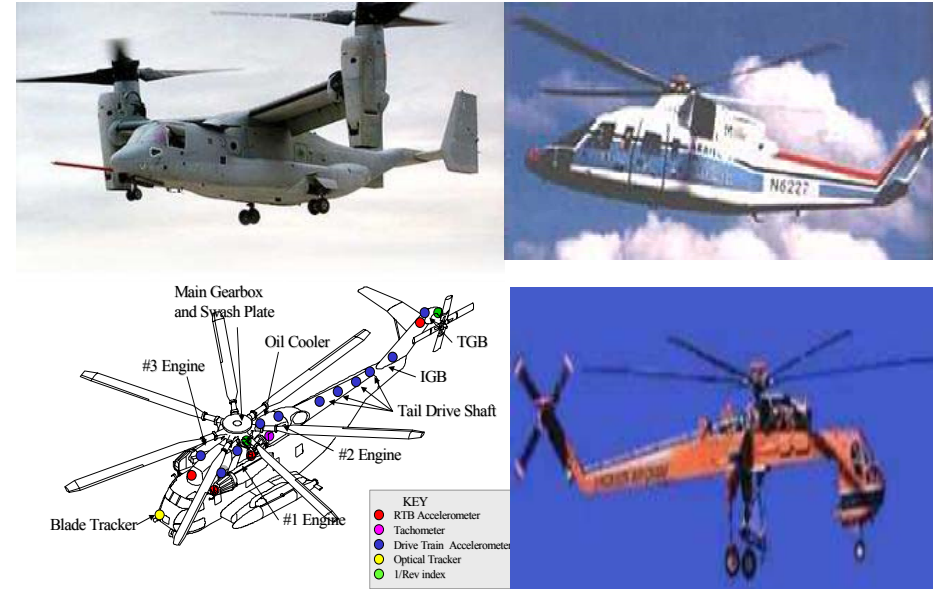
Rotorcraft Structural Integrity and Safety



HUMS R&D Requirements

Program Objectives:

- ➔ Provide Aircraft Certification Office with technical information including data and validated processes for HUMS installation, maintenance credit, and continued airworthiness plan.



Technical Approaches:

- ➔ Collaborate with HUMS community to conduct R&D and collect HUMS data.
- ➔ Validate and transfer HUMS technologies for certification and compliance.

Support:

- ➔ Addition/revision of guidance materials for Transport Category Helicopters
- ➔ Development of typical usage spectrum for design requirements and certification
- ➔ DT certification requirements

Development of HUMS R&D Strategy and Execution Plan

- Industry's HUMS and R&D Perspectives
 - Helicopter OEM's and HUMS Supplier
- FAA's HUMS and R&D Perspectives
 - FAA-industry combined assessment of current state of HUMS technology
 - FAA's independent process to identify and prioritize HUMS R&D needs

Elements of FAA's HUMS R&D Strategy and Execution Plan

- ➔ **Technology assessment and gap analysis**
 - ➔ HUMS technology matrices
 - ➔ Technology assessment criteria
- ➔ **Prioritization of identified R&D needs**
 - ➔ Prioritization criteria
- ➔ **Detailed HUMS R&D execution plan**
 - ➔ Prioritized R&D tasks, outputs, and ROM
 - ➔ R&D performance metrics and exit criteria
- ➔ **HUMS 5/10 Year R&D Roadmap**

OPERATIONAL DEVELOPMENT OF HUMS

Hardware

Software

Sensors

Airborne Systems

Data Management and Operation

Diagnostics and Monitoring

Multi Functional, Embedded, Vibration	Analog/Digital Conversion Unit	Component Usage Tracking	Rotor Track and Balance
Temperature, Strain, Torque, Humidity	Electromagnetic Compatibility Test Plan	HUMS-Non-HUMS Usage Tracking	Exceedance, Trending, Vibration
Data Transmission, Wireless, Networking	Cockpit Warning and Display Devices	Data Processing Requirements	Corrosion Detection
Rotor Azimuthal & Rotor Blade Position	Information Display Management	Data Operation Acquisition Requirements	Time and Cycle Usage Monitoring
Debris Detection and Oil Condition	Cockpit Voice, Flight Data Recorders	Data Integrity	Translated Load Monitoring
Corrosion Detection and Monitoring	HUMS False Alarm Rates	Data Transfer Integrity	Residual Life Based on HUMS
Direct Load Measuring/Low Speed	COTS Assessment and Mitigation Actions	COTS Operating System For GBS	Component Remaining Life Prior to HUMS Implementation
Crack/Damage Detection	Airborne System Functionality Partition	COTS Software Service History Criteria and IVM	Mechanical Fault Detection
Sensor Interrogation and Calibration	Software Requirements and Acceptance	Independent Verification Means (IVM)	Structural Crack/Damage Detection
Maintenance Data Computer	System Automated Testing	Data Transfer and Significance of Web-Enable Application	Automated Diagnostics/Rationale
Bearing Monitoring Processing	Architecture Standardization	Maintenance Management	
Ground-Based Stations (GBS) and Accessories		Electronic Part Tracking/Maint Logs	Usage Tracking and Credits
Software Requirements, Acceptance	COTS GBS Assessment, Guidance	Operational and Logistics Optimization	Usage Based Maintenance
Security Concerns For Non-Dedicated GBS	COTS Hardware Service History Criteria and Independent Verification		
GBS Functionality Partition	Personal Maintenance Aide		
Personal Computer (PC)	GBS Automated Testing		
Data Update Frequency	HUMS Component Partition for Certification		
System Architecture Standardization	Display and Data Transmission Devices		

COMMERCIAL VALIDATION OF HUMS

Algorithms and Methodologies

Safety Monitoring	Usage/Credit Validation	Diagnostics, Health, and/or Prognostics	
Debris, GW, CG Measurements	Metallic Damage Tolerance (DT) & HUMS - Regime/Load Based Issues and Technology Demonstration	RTB, Damage Detection	Mechanical Fault/Crack Detection
Flight Manual Exceedances Procedures	Direct/Indirect Evidence Requirements	Integrated Aircraft Health Assessment	Prognostics Physical Modelings and Software Tools for Drive Systems
HUMS Safety Assessment Process (FHA/PSA/SSA), Regime Recognition	Controlled Introduction Plan to Service for Full Validation of Credit, Credit Validation	Exceedance, Trend Analysis, Mixed Failure Modes, Corrosion Detection	Integrated Prognostics/Diagnostics for Fatigue Critical Components
HUMS Minimum End-to-End Performance, Advanced Sensor Validation Criteria	Composite DT & HUMS - Regime/Load Based Issues and Technology Demonstration	Component Remaining Life Based on HUMS Process	Prognostics Database Methods, Automated Diagnostic and Rationale
End-to-End HUMS Systems and Accessory Requirements	Metallic Safe Life & HUMS - Regime/Load Based Issues and Technology Demonstration	Instructions For Continued Airworthiness	
HUM Systems Intallation (Airborne, Sensors, Ground Systems, Software)	Composite Safe Life & HUMS - Regime/Load Based Issues and Technology Demonstration	Mitigation Action for Certification Limitations	Procedures for Revising and Using Minimum Equipment List for HUMS
Physics of Proposed Credits (e.g., Collection of Data)	Component Crack Growth and Anomaly Modeling, Engine Cycle Counting	Owener/Operator's HUMS Program to Existing Maintenance and/or Inspection	Instructions for Continued Airworthiness in Accordance with FAR/JAR Part 27/29 Appendix A
ICA for Validation of Approved Credit Throughout Service Use	Advanced Rotor Tuning/Flight Hours Calculation/Propabilistics Lifting-HUMS Approach	Troubleshooting and Testing of HUMS	Master Minimum Equipment List Revision

HUMS Technology Matrices – Developed



HUMS ASSESSMENT AND GAP ANALYSIS

GAO Technology Readiness Levels

Normally at TRL 9, but can be lower

Years to bring technology to required TRL

Technology Maturation Risk

(Required - Current) TRL

Certified?

Technology Maturation Risk (TMR)

TRL	Risk	TMR
0	High	3
1	High	3
2	High	3
3	Medium	2
4	Medium	2
5	Medium	2
6	Low	1
7	Low	1
8	Low	1
9	No Risk	0

HUMS TECHNOLOGY ASSESSMENT AND GAP ANALYSIS								IDENTIFIED TECHNOLOGY NEEDS
Technology Assessment			Current State of Technology			AC Support Criteria		
Current TRL (0 to 9)	Required TRL (1 or 9)	Years To Fully Operational (or to TRL 9)	Technology Risk (0, 1, 2, or 3)	Technology Gaps	Certification Readiness Ready = 0 Not Ready=1	Applicable to HUMS AC? Yes = 0 No = 1	Is this an R&D task? Yes = 0 No = 1	

Addressing AC 29-2C, MG-15?

Must be research in nature

Selected for
prioritization

	HUMS TECHNOLOGY ASSESSMENT AND GAP ANALYSIS								IDENTIFIED TECHNOLOGY NEEDS
	Technology Assessment			Current State of Technology			AC Support Criteria		
	Current TRL (0 to 9)	Required TRL (1 or 9)	Years To Fully Operational (or to TRL 9)	Technology Risk (0, 1, 2, or 3)	Technology Gaps	Certification Readiness Ready = 0 Not Ready=1	Applicable to HUMS AC? Yes = 0 No = 1	Is this an R&D task? Yes = 0 No = 1	
Op Dev of HUMS	7	9	2	1	2	28%	85%	89%	
Hardware	7	9	2	0.9	2	30%	83%	88%	Hardware
Sensors	6	9	3	1.2	5	39%	72%	100%	Sensors
Multi Functional	6	9	5	1	3	1	0	0	Multi Functional
Embedded	7	9	10	1	2	1	0	0	Embedded
Temperature	9	9	5	0		0	1	0	No
Strain	9	9	0	0		0	0	0	No
Torque	9	9	0	0		0	1	0	No
Vibration	9	9	0	0		0	0	0	No
Rotor Azimuthal Position	9	9	0	0		0	0	0	No
Rotor Blade Position	9	9	0	0		0	0	0	No
Humidity	0	9	5	3	9	1	1	0	No
Debris Detection and Oil Condition	9	9	0	0		0	1	0	No
Corrosion Detection and Monitoring	6	9	5	1	3	1	1	0	No
Direct Load Measuring (e.g., Gross Weight (GW), Center of Gravity	2	9	2	3	7	1	0	0	Direct Load Measuring (e.g., Gross Weight (GW), Center of Gravity
Low Speed Sensors	2	9	2	3	7	1	0	0	Low Speed Sensors
Structural Crack/Damage Detection	2	9	5	3	7	1	0	0	Structural Crack/Damage
Dynamic Component Crack/Damage Detection	2	9	5	3	7	1	0	0	Dynamic Component Crack/Damage Detection
Sensor Interrogation and Calibration	6	9	4	1	3	1	0	0	Sensor Interrogation and Calibration
Rotating Data Transmission	6	9	5	1	3	1	0	0	Rotating Data Transmission
Data Transmission, Wireless, and Networking	7	9	5	1	2	1	0	0	Data Transmission, Wireless, and

	HUMS TECHNOLOGY ASSESSMENT AND GAP ANALYSIS								IDENTIFIED TECHNOLOGY NEEDS
	Technology Assessment			Current State of Technology			AC Support Criteria		
	Current TRL (1 to 9)	Required TRL (1 or 9)	Years To Fully Operational (or to TRL 9)	Technology Risk (0, 1, 2, or 3)	Technology Gaps	Certification Readiness Ready = 0 Not Ready=1	Applicable to HUMS AC? Yes = 0 No = 1	Is this an R&D task? Yes = 0 No = 1	
Op Dev of HUMS	7	9	2	1	2	27%	85%	89%	
Software	7	9	2	1.0	2	25%	88%	91%	Software
Data Management and Operation	7	9	2	1.1	2	8%	92%	92%	Data Management and Operation
Component Usage Tracking	7	9	5	1	2	1	0	0	Component Usage Tracking
Usage Tracking of Components Transferred From Non-HUMS-RC to HUMS RC and Vice Versa	2	9	2	3	7	1	0	0	Usage Tracking of Components Transferred From Non-HUMS-RC to HUMS RC and Vice Versa
Data Processing Requirements	8	9	1	1	1	1	0	0	Data Processing Requirements
Data Synchronization	9	9	0	0		0	1	0	No
Data Storage & Backup	7	8	1	1	1	1	0	1	No
Security/Access Control Methods/Procedures	7	8	1	1	1	1	0	0	Security/Access Control Methods/Procedures
Data Acquisition Operational Requirements	8	9	3	1	1	1	0	0	Data Acquisition Operational Requirements
Data Integrity - Procedures for Addressing Missing, Unrecognized Data, Out-of- Range Data	8	9	2	1	1	1	0	0	Data Integrity - Procedures for Addressing Missing, Unrecognized Data, Out-of- Range Data
Data Transfer Integrity (e.g., Data Corruption During Transfer of Data from Airborne to GBS)	8	9	1	1	1	1	0	0	Data Transfer Integrity (e.g., Data Corruption During Transfer of Data from Airborne to GBS)
Isolation of HUMS Software From COTS OS For GBS	8	9	2	1	1	1	0	0	Isolation of HUMS Software From COTS OS For GBS
COTS Software Service History Criteria and IVM	8	9	2	1	1	1	0	0	COTS Software Service History Criteria and IVM
Data Transfer and Significance of Web-Enable Application	8	9	1	1	1	1	0	0	Data Transfer and Significance of Web-Enable Application

HUMS Assessment Results

HUMS SUB-CATEGORIES	Certification Readiness	Applicability to HUMS AC	R&D
Sensor	33%	72%	100%
Airborne Systems	23%	77%	77%
Ground-Based Stations and Accessories	29%	100%	86%
Data Management and Operation	8%	92%	92%
Diagnostics and Monitoring	27%	91%	100%
Maintenance Management	40%	80%	80%
Safety Monitoring	17%	83%	50%
Structural Usage Monitoring and Credit Validation	12%	59%	88%
Diagnostics, Health, and Prognostics	13%	47%	100%
Continued Airworthiness Instructions	0%	100%	0%
On-Board Warnings, Responses and Procedures	<u>0%</u>	<u>100%</u>	<u>100%</u>
Overall HUMS Assessment:	18%	82%	79%

HUMS R&D Needs – Identified



FAA PRIORITIZATION PROCESS

Prioritization Criteria

- ➔ Is the technology really needed for certification?
 - ➔ e.g., cockpit warning devices may not.
- ➔ What is the impact level of this research on HUMS functionality?
 - ➔ e.g., ground system functionality partition technique
 - not improving HUMS functionality.
- ➔ Is the research essential for maintenance reduction?
 - ➔ e.g., embedded sensor not really essential.
- ➔ Will the research improve rotorcraft operation readiness?
 - ➔ e.g., low speed sensors not relevant to operation readiness.

IDENTIFIED
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Rating	
0	No Value
1	Important
2	Very Important
3	Essential

Calculated Ranking Score of Each Criterion

Individual Rating Score x Weighing Percentage

Total Ranking Score of Each HUMS Element

Summation of All Ranking Scores For Each HUMS Element

Sample

HUMS Element	Cert. Need	Functionality Impact	Maint Impact	Readiness	Rating Scores	Rating Levels
Flight Regime	3	3	3	2	2.8	Essential
	0.84 +	0.78 +	0.78 +	0.38 +		

Prioritization Scheme		
Rating Scores	Rating Levels	Results
0.0	No Value	Not selected
0.1	No Value	Not selected
0.2	No Value	Not selected
0.3	No Value	Not selected
0.4	No Value	Not selected
0.5	No Value	Not selected
0.6	Long-Term	10th Year
0.7	Long-Term	10th Year
0.8	Long-Term	9th Year
0.9	Long-Term	9th Year
1.0	Long-Term	8th Year
1.1	Long-Term	8th Year
1.2	Long-Term	7th Year
1.3	Long-Term	7th Year
1.4	Long-Term	6th Year
1.5	Long-Term	6th Year
1.6	Useful	5th Year
1.7	Useful	5th Year
1.8	Useful	5th Year
1.9	Very Useful	4th Year
2.0	Very Useful	4th Year
2.1	Very Useful	4th Year
2.2	Important	3rd Year
2.3	Important	3rd Year
2.4	Important	3rd Year
2.5	Very Important	2nd Year
2.6	Very Important	2nd Year
2.7	Very Important	2nd Year
2.8	Essential	1st Year
2.9	Essential	1st Year
3.0	Essential	1st Year

<div> <div>IDENTIFIED</div> <div>TECHNOLOGY NEEDS</div> </div>	HUMS R&D PRIORITIZATION						HUMS R&D Planning										
	Need	Impacts	Essential		Ranking		Project Start/End and Duration (Years)										Out-Years
	for	on HUMS	For HUMS	Improved	Scores of	Rating											
	Certification	Functionality	Maint Red	Readiness	R&D Needs	Levels	Short-Term					Long-Term					
	(0, 1, 2, 3)	(0, 1, 2, 3)	(0, 1, 2, 3)	(0, 1, 2, 3)	(Max= 3)		1	2	3	4	5	6	7	8	9	10	11th - >
Op Dev of HUMS	28%	26%	26%	19%													
Hardware	2.1	2.5	2.1	1.3	2.0												
Sensors	2.1	2.3	2.2	2.0	2.2												
Multi Functional	1	1	1	1	1.0	Long-Term, 8th								5	4	3	2
Embedded	1	1	1	1	1.0	Long-Term, 8th								10	9	8	7
No																	
No																	
No																	
No																	
No																	
No																	
No																	
No																	
No																	
Direct Load Measuring (e.g., Gross Weight (GW), Center of Gravity (CG))	3	3	2	3	2.7	Very Important	2	1									
Low Speed Sensors	1	1	1	0	0.8	Long-Term, 9th								2	1		
Structural Crack/Damage Detection	3	3	3	3	3.0	Essential	5	4	3	2	1						
Dynamic Component Crack/Damage Detection	3	3	3	3	3.0	Essential	5	4	3	2	1						
Sensor Interogation and Calibration	3	3	3	3	3.0	Essential	4	3	2	1							
Rotating Data Transmission	2	3	3	2	2.5	Very Important		5	4	3	2	1					
Data Transmission, Wireless, and Networking	2	3	3	2	2.5	Very Important		5	4	3	2	1					

FAA HUMS R&D ROADMAP

Legends:

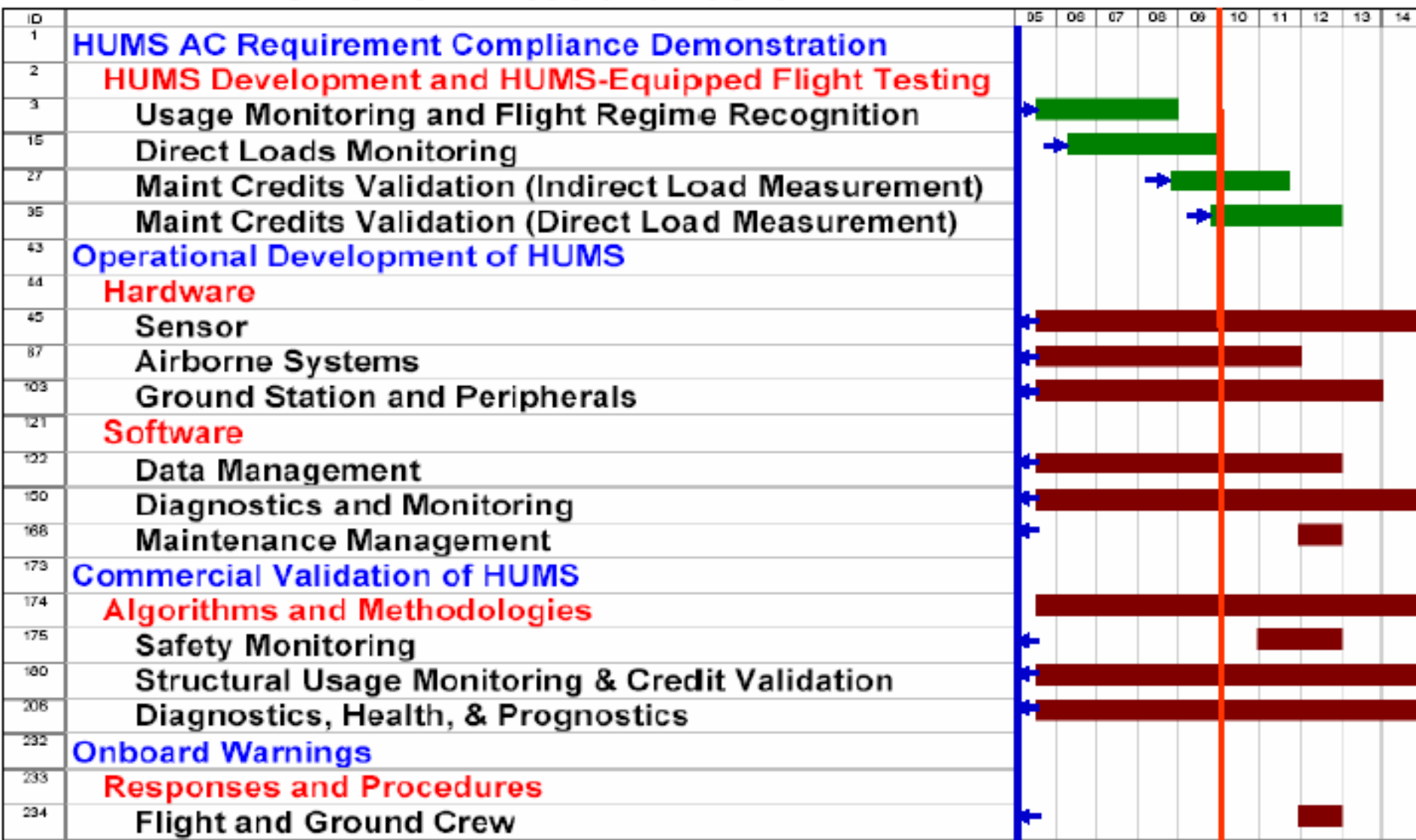
Technology Demonstration

Technology Development
And/or Validation

HUMS R&D Roadmap

HUMS R&D Areas and Tasks

Short

Long
Term

HUMS AC Requirement Compliance Demonstration

Technical Objectives:

- AC compliance demonstration
 - Usage and flight regime recognition
 - Load monitoring
 - Maintenance credit validation



Technical Approaches:

- Establish intended purpose of HUMS.
- Develop certification and mitigation strategies to address AC requirements.
- Conduct HUMS-equipped flight tests.

Outputs:

- Validated developed processes and technologies demonstrating HUMS AC compliance
- Substantiated usage and maintenance credit

HUMS AC Requirement Compliance Demonstration

HUMS R&D Areas and Tasks

Short

Long
Term

ID		05	06	07	08	09	10	11	12	13	14
1	HUMS Development and Equipped-Flight Testing										
2	Usage Monitoring and Flight Regime Recognition										
14	Direct Loads Monitoring										
26	Maint Credits Validation (Indirect Load Measurement)										
34	Maint Credits Validation (Direct Load Measurement)										

Priority:

High

Medium

Low



Development of HUMS

Operational Requirements

Technical Objectives:

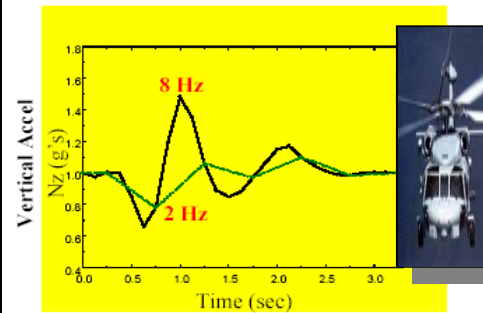
- Determination of HUMS airborne and ground-based system requirements and processes including:
 - Hardware and software

Technical Approaches:

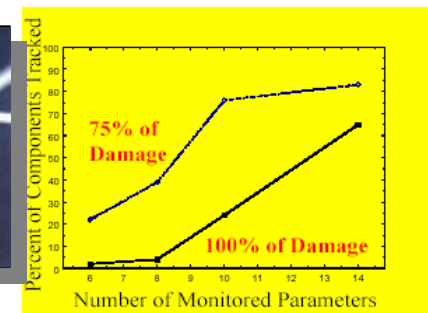
- Direct load measuring
- Mechanical and structural fault detection/isolation
- Software requirements and acceptance
- Ground-based station automated testing

Data Rate and Parameter Assessments

Data Rate Assessments
Effect of Inadequate Data Rate



Monitored Parameter
Damage Assessments



Outputs:

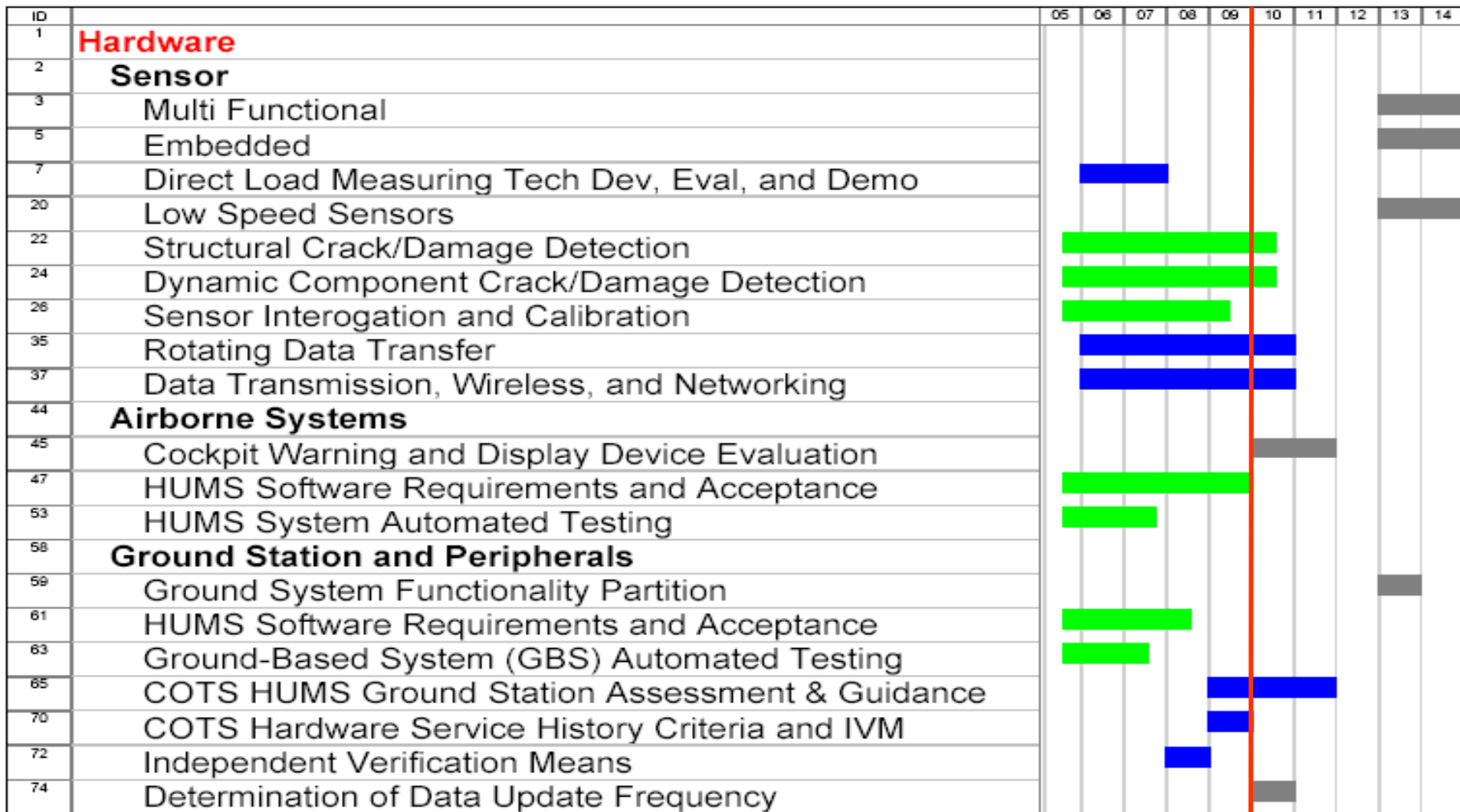
- HUMS operational requirement inputs for certification

Development of HUMS Operational Requirements - Hardware -

HUMS R&D Areas and Tasks

Short

Long
Term

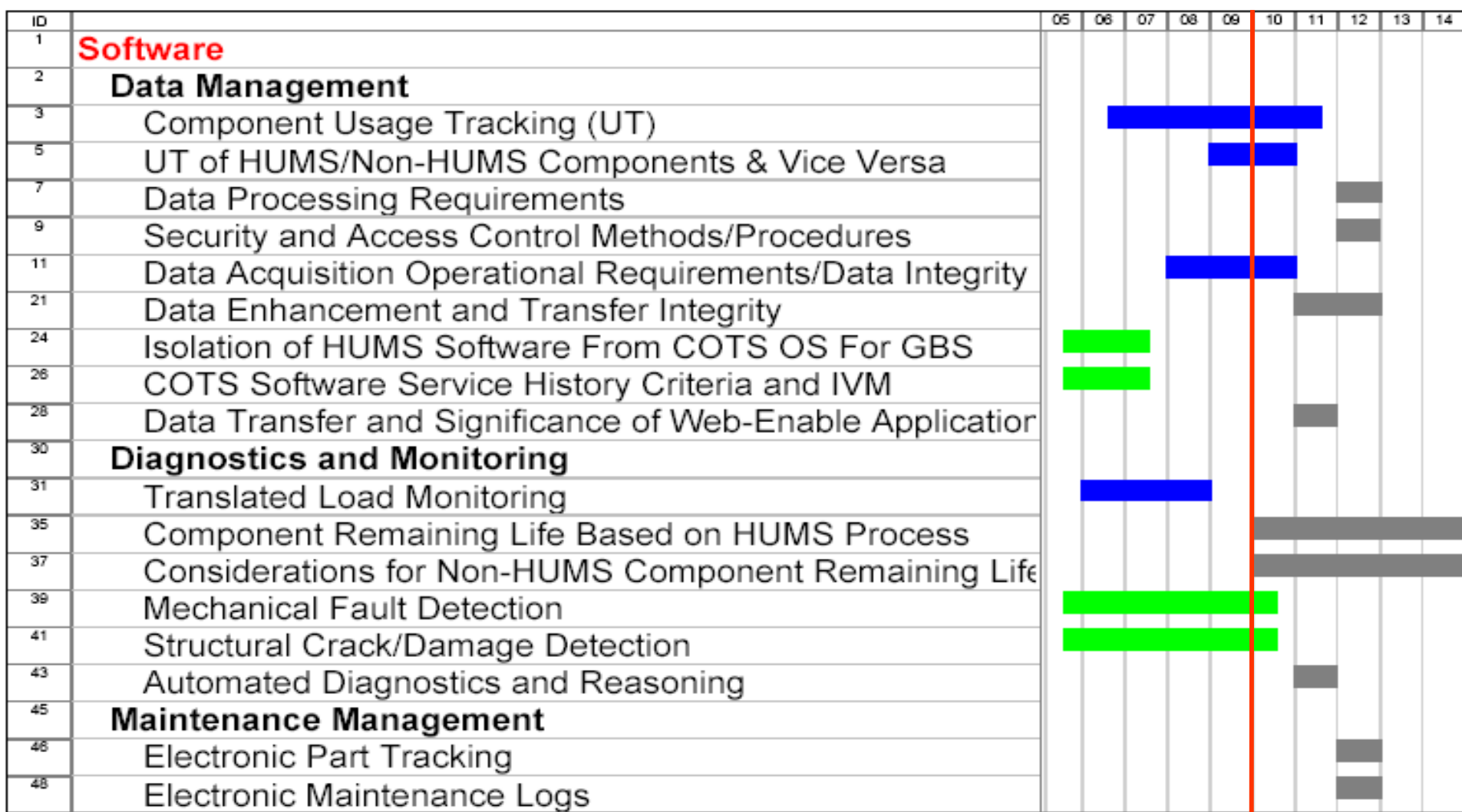


Development of HUMS Operational Requirements - Software -

HUMS R&D Areas and Tasks

Short

Long
Term



Commercial HUMS Validation

Technical Objectives:

- ➔ Evaluation of technologies including algorithms, methodologies, and processes for usage monitoring and maintenance credit



Technical Approaches:

- ➔ Evaluate:
 - ➔ Flight condition recognition algorithm/methodologies for usage-based maintenance
 - ➔ Mechanical and structural fault detection/isolation
 - ➔ Component remaining life based on HUMS process

Outputs:

- ➔ HUMS usage and maintenance credit validation processes for certification
- ➔ Data and methodologies to support Usage and FCR, Load Monitoring, and Maintenance Credit AC Compliance Demonstrations

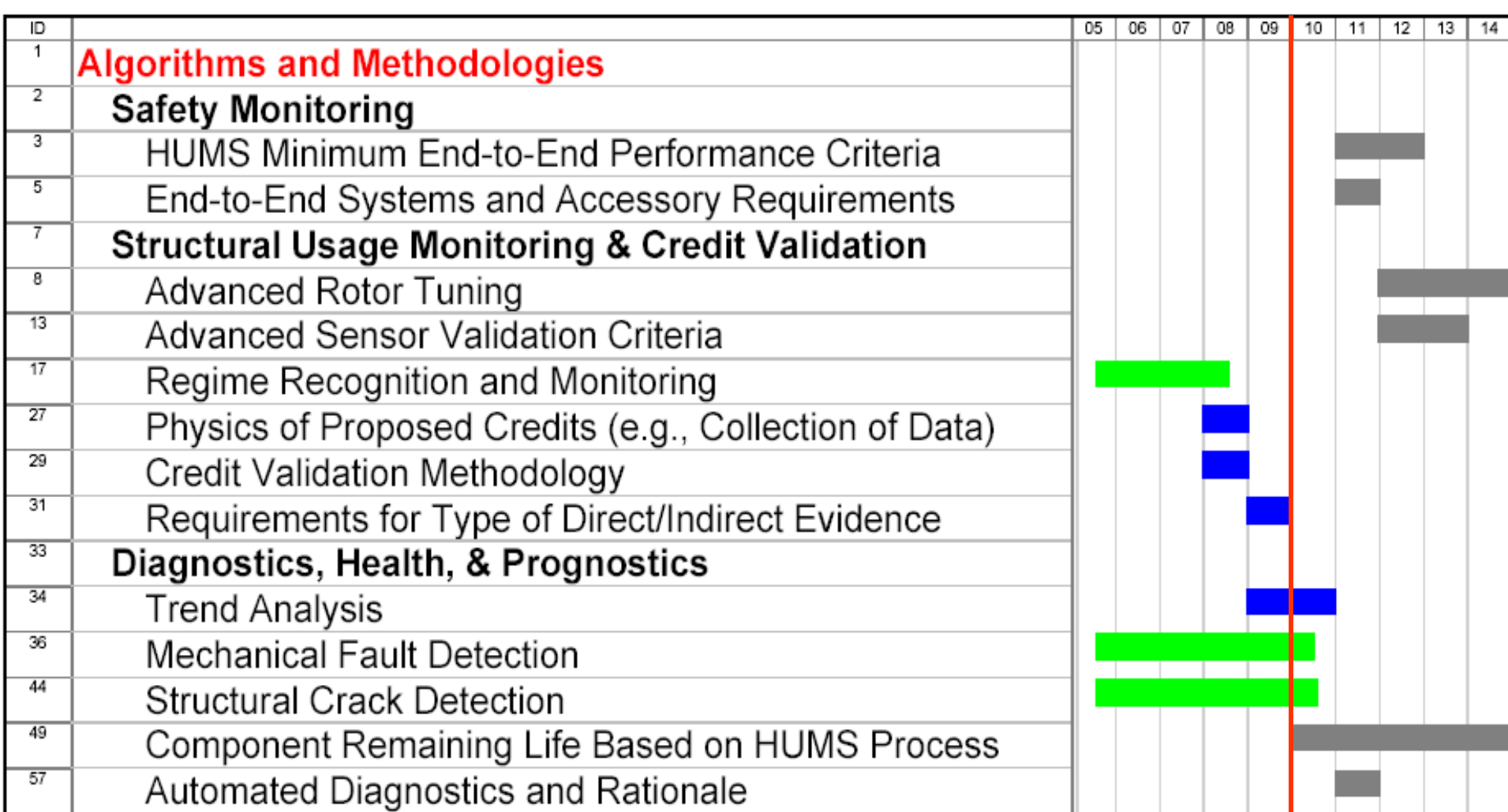
Commercial HUMS Validation

- Algorithm and Methodologies -

HUMS R&D Areas and Tasks

Short

Long
Term



HUMS Onboard Warnings

Technical Objectives:

- ➔ Assessment of onboard display devices to determine their reliability, functionality, and required response or action to displayed/audible advisories/warnings



Technical Approaches:

- ➔ Evaluate types of devices and information to be displayed or audible.
- ➔ Assess pilot interface with operational aspects of the system.
- ➔ Study pilot's response or reaction to displayed/audible advisories/warnings.

Outputs:

- ➔ Requirements for onboard advisory/warning and display systems or devices
- ➔ Guidelines for pilots or ground-based personnel required to respond to onboard advisories and warnings

Onboard Warnings

- Responses and Procedures -

HUMS R&D Areas and Tasks

Short Long Term

ID		05	06	07	08	09	10	11	12	13	14
1	Responses and Procedures										
2	Flight and Ground Crew										
3	Impact of Displayed HUMS Information on Pilot Workload										
5	Pilot Reaction on Warnings										
7	Procedures for Responding to Warnings										

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Questions?

FAA 2005 HUMS Activities and BAA Projected Schedules

Outputs/Tasks	Jan	Feb	Mar	Apr	May	Jun	Jul
FAA HUM R&D Strategic Plan – First Draft	<u>01/28</u> 						
Internal Management Review							
Second Draft		<u>02/25</u> 					
Final Draft		<u>03/11</u> 	<u>FAA Editing and Publication Process</u> 				
Development of HUMS R&D Broad Agency Announcement							
<u>White Papers Solicitation</u>	<u>White Papers Due 03/25</u> 						
				<u>WP Eval & Selection 04/01</u> 			
<u>Proposals Solicitation</u>			<u>Proposals Due 04/29</u> 				
					<u>Eval & Selection 05/13</u> 		
HUMS R&D Awards						<u>06/17</u>	
HUMS R&D Commencement							

FAA Contract Opportunities website

<http://www.asu.faa.gov/faaco/index.cfm?cookieTested=TRUE>